SPE 108195

Locating and Repairing Casing Leaks with Tubing in Place - Ultrasonic Logging and Pressure-Activated Sealant Methods

J.E. Johns/TecWel: D.N. Cary/Seal-Tite International: J.C. Dethlefs/ConocoPhillips: B.C. Ellis/Seal-Tite International: M.L. McConnell/ConocoPhillips: G.L. Schwartz/ConocoPhillips

This paper was prepared for presentation at Offshore Europe 2007 held in Aberdeen, Scotland, U.K., 4–7 September 2007.

Abstract

When operators are faced with issues involving casing leaks, a typical course of action is to pull the tubing and make efforts to identify and locate the source of the leak by logging or other mechanical means. If the leak source can be successfully located, a mechanical method is generally employed to patch the leaking casing. This methodology is time consuming and expensive.

Locating casing leaks with the tubing in place using conventional logging techniques has historically been difficult. Where some tools, such as temperature tools, may provide an indication of an anomaly in annuli, the data may be subjective or the leak may be too small to measure. When active, a leak will produce a spectrum of sonic frequencies that may be either audible, ultrasonic or both. Ultrasonic energy will pass through steel but travels relatively short distances. A tool developed around these principles has been successful in accurately locating casing leaks behind tubing.

Pressure-activated sealants have been used for a number of years to cure a wide variety of leaks in casing, tubing, control lines, and well heads as well as micro-annulus leaks in cement. For the purpose of repairing a casing leak behind tubing, the liquid sealant may be pumped into the annulus and displaced to the leak site. The liquid sealant will not polymerize until it is exposed to the differential pressure through the leak site. Knowing the leak rate, pressure and precise location of the leak aids in the selection of the sealant formulation and deployment method. This helps to reduce overall repair cost as well as increase the probability of a successful repair.

This paper will describe the ultrasonic method of leak detection and the method of curing leaks with pressure activated sealant with tubing in place. Case histories will be presented where these methods were employed to repair casing leaks without removing the tubing.

Introduction

Perhaps the most challenging well integrity issue with which operators deal with today are casing leaks. Not only are the methods to repair these types of leaks without pulling the tubing limited, but the detection of these leaks using conventional logging methods with the production tubing in place is practically impossible. A common diagnostic methodology is to rely on some fairly subjective logging data and pressure responses to determine where a pressure barrier is leaking. Following this, cement is pumped down the annulus or through punched tubing in an attempt to seal off the leak. This process, along with other hardening sealant methods, can be problematic. Additionally, using this method will also make other operations or future workovers difficult or impractical.

Pressure activated sealants have been used on numerous occasions to repair casing leaks with the tubing in place. A major advantage in utilizing this technology is that the sealant will only solidify where the leak is active. In addition, the material is easily removed by mechanical means and will not add difficulty to future workover operations if required.

As is true with other remediation methods, a complete understanding of the leak source is critical when planning a pressure activated sealant operation. This is especially true when dealing with leaks behind the tubing. Optimal sealant formulations may be selected along with deployment methods for maximum affect. While rate and differential can be determined by pressure and well bore data, a leak behind casing is more complex. Detection of casing leaks is difficult using conventional logging techniques. These leaks will produce no reading on spinners (for obvious reasons) and may not produce temperature changes that are of a magnitude to confirm a leak point. This is true even with fairly large leaks (>1gpm). Conventional noise logs can detect fluid or gas movement, but must be used in a stationary mode and distant noise sources may confuse interpretation. Tracer logs may be used but can also produce imprecise results.

The ultrasonic leak detection method has been proven to be useful in detecting leaks behind casing with a high degree of accuracy. This suggests that it would be a useful tool in evaluating wells for repair using a pressure activated sealant method where accurate spotting of the treatment is critical.

Ultrasonic Leak Detection Method[1]

The following section briefly discusses how a leak produces an ultrasonic signature and the method of locating leaks with a passive ultrasonic logging tool.

Ultrasound Production by Leaks

The properties of a leak determine if it will produce an ultrasonic signature, an audible signature, or both. The factors involved in producing an ultrasonic signature are related to leak rate, differential pressure across the leak, leak path geometry, and the corresponding media. The presence of turbulent flow at a leak point has been determined to produce an ultrasonic signature. Ultrasound, like audible sound, will pass through steel, gas, liquid, and other media. Although attenuation is present in these media, it is typically small enough to allow ultrasound detection by equipment available today.

Ultrasonic Sensor

Piezoelectric crystal sensing devices have been used for a number of years in many applications. For this tool, a sensor was utilized that detects a spectrum of frequencies including those typically produced by leaks. The sensor used is capable of detecting the sound generated by a leak through various media encountered in a down hole environment.

Digital Signal Processing

The piezoelectric sensor produces small voltage responses proportional to the signal strength produced by the sound generated at the leak point. In order to isolate the frequencies of interest, the small piezoelectric analog signal is amplified and passed through a digital signal processing unit within the tool. The processing unit is equipped with a large amount of flash RAM (random access memory) running a series of modular signal processing programs. The programs consist of a series of band-pass algorithms that focus on the ultrasonic frequencies that are typically produced by leaks. The filtering algorithms remove unwanted background energies caused by mechanical noise or other interference. Virtually all audible frequencies are filtered out. The result is a fully digitized signal of the leak signature which is then transmitted up-hole via a conventional electric line telemetry system to a surface read out system, producing a graphical representation of the leak signature. The tool may also be deployed on slick line, coiled tubing, or by other methods requiring memory data storage.

Tool Response

The graphical representation of the tool response shows three frequency windows of investigation (**Fig. 1**). Three traces used are the total energy level, a medium-high frequency range, and a very high frequency range (ALD A, B and C, traces respectively). These are unitless measurements of signal strength. A casing collar locator (CCL) is also presented for correlation purposes.

The leak signature shown in Figure 1 is a tubing leak in a water injection well with a magnitude of approximately 0.08 gpm with a differential pressure across the leak of 900-1200 psi.

Pressure Activated Sealant

Pressure Activated Sealants have been successfully used to perform a variety of repairs in oilfield equipment. Both oil-based and water-based sealants are employed depending on the system conditions. By adjusting the specific gravity and viscosity of the sealant, methods and procedures may be developed which precisely place the sealant at the previously determined leak site. Once placed, manipulation of the pressure differential across the leak site then activates the sealant to complete the repair.

The sealant only activates at the point of pressure differential, converting to a +- 80 durometer elastomer within the leak path. Excess sealant not exposed to pressure differential (e.g. the sealant remaining in the annulus) remains in the fluid state. This fluid can be left as part of the annular fluid system, or can be flushed from the system if the annulus is required for other uses such as gas lift.

The sealants are custom blended for each repair; therefore precise pre-job diagnostics are important to ensure that the sealant blend and procedure is correct to ensure optimum results.

Case Histories – North Slope, Alaska

Avoiding a rig work over can represent a considerable savings to any operator. This is particularly true on the North Slope where work over operations involving pulling of production tubing can cost between one and three million dollars depending upon the complexity of the operation. This section will cite two specific case histories were leaks were detected behind the tubing and cured with the tubing in place.

Casing Leak Behind Tubing (Well A)

Ultrasonic Leak Detection. Well A (**Fig. 2**) is an active water and gas injection well completed with 3.5" tubing inside 7" casing. The "A" annulus failed a mechanical integrity test and was shut in due to loss of a barrier.

During logging operations, a mechanical integrity test was emulated by maintaining the "A" annulus pressure between 3300 and 2800 psi. A calculated leak rate was established between 0.21 and 0.39 gpm. A typical leak signature was located at 2574' measured depth (MD) during a dynamic pass of 30 ft/min, (**Fig. 3**).

In order to further confirm the leak location, stationary readings are taken through an interval above and below the leak point (**Fig. 4**). The center scale, as with all stationary logs presented, has units of time in seconds. The depths are annotated. The tool was positioned at 2' intervals above and below the leak to verify the leak location. Note the change in signal strength over these intervals demonstrating the resolution of the tool.

When the tool is placed precisely at the leak point and the annular pressure is manipulated (by bleeding or pressuring up the annulus), the change in signal strength can be observed associated with the leak magnitude (**Fig. 5**). This measurement, along with the tubing and annulus pressure response monitoring, confirm in which barrier the leak is located. As the pressure is decreased in the annulus, it can be seen that the signal strength diminishes. As the pressure is increased, the signal strength increases.

Upon further analysis of other well data available, it was determined that the leak signature was in close proximity with a casing collar behind the tubing. The ultrasonic log results, combined with historic data, created a clear picture of the leak location and probable damage mechanism.

Pressure Activated Sealant Deployment. Once the location and characteristics of the leak location was identified, repair options could be reviewed. Within the history of pressure activated sealants, thread leaks typically have a much higher chance of long term success than leaks caused by corrosion (high surface area, low cross-sectional area). Therefore the knowledge that the leak was most likely in a casing collar increased the confidence level in a pressure activated sealant repair.

To perform the repair, a water based sealant weighing approximately 8.5 ppg was selected. In order to accurately place the sealant across leak, a delivery "platform" was created using brine heavier than the sealant, approximately 9.6 ppg. A plug was set in the tubing below a gas lift mandrel at 6665' and the gas lift dummy was pulled to expose a circulation path between the tubing and annulus. The 9.6 ppg brine was then circulated until the annular fluids were fully displaced with brine.

A 3 bbl pill of 8.5 ppg pressure activated sealant was injected into the annulus (equivalent to approximately 120' in 7" x 3 ½" annulus). The sealant was displaced to the leak site down the annulus using 80 bbls of diesel (6.8 ppg) while returns were taken from the tubing. The bottom of the sealant was spotted at approximately 2550', 24 feet above the leak site. Tubing returns were closed and additional diesel was pumped into the annulus in order to increase the squeeze pressure to 3000 psi. Annulus brine was squeezed through the leak until the sealant arrived at the leak site and started the activation process.

Over the space of 18 hours the pressure drop through the leak decreased from 130 psi/hour to 30 psi/hour. At that point the gas lift dummy was reinstalled and the well was returned to active water injection. The well subsequently passed a 2800 psi Annular Mechanical Integrity Test (MIT), with no pressure bleed off noted over 24 hours. The annular pressure was then reduced to 800 psi and the well returned to normal water injection service.

Casing Leak Behind Tubing (Well B)

Ultrasonic Leak Detection. Well B (**Fig. 6**) is also an active injection well completed with 3.5" tubing inside 7" casing. The well was initially restricted from MI service and then shut-in due to a loss of barrier indicated from a failed Mechanical Integrity Test.

During logging operations, the leak was established by maintaining the "A" annulus pressure between 2500 and 2000 psi. using diesel. The leak rate established ranged from 0.44 and 0.83 gpm. A leak signature was located at 3060' measured depth (MD) during a dynamic pass of 30 ft/min, (**Fig. 7**).

The leak location was confirmed by stationary readings and manipulating the leak rate (**Figs. 8 & 9**).

A correlation of the leak depth with the casing tally indicated that the leak was in proximity to a landing collar installed in the casing string. After location and analysis of the leak, the well was scheduled for application of pressure activated sealant to cure the leak.

Pressure Activated Sealant Deployment. As mentioned in the previous case history, an accurate knowledge of the leak location and characteristics provided confidence in the selection of pressure activated sealants as the best repair option. A similar procedure as the previous example was employed. A 3 bbl pill of 8.5 ppg pressure activated sealant was "floated" on 9.6 ppg brine and displaced to the leak location with 70 bbls of diesel. Then 1.8 bbls of diesel was used to pressure the annulus to 3000 psi. The initial annulus pressure drop was 1300 psi in 30 minutes. After 4 hours of maintaining annulus pressure at 3000 psi the sealant reached the leak location and the pressure drop fell to 200 psi in 30 minutes.

After an additional 8 hours of sealant cure time the dummy was replaced in the gas lift mandrel and the annulus pressure reduced to the required test pressure of 2000 psi. The pressure was monitored over the next 24 hours with no bleed off noted, indicating a successful annulus MIT. At this point the annulus pressure was reduced to 800 psi and the well was returned to normal water injection service. The annulus pressure history during the repair is shown in Figure 10.

Conclusions

- Ultrasonic leak detection has proven to be effective in locating leaks in the casing behind tubing.
- Pressure activated sealant is an effective alternative in the repair of casing connection leaks.
- Knowledge of the leak location and characteristics provided confidence in the selection of pressure activated sealants as the preferred repair mechanism, and allowed an efficient repair procedure to be developed.
- The combination of these processes provided the Operator with a leak repair which restored the annular mechanical integrity at a fraction of the cost of conventional rig repair.

Acknowledgements

The authors thank the management of ConocoPhillips Alaska, Inc., and other Unit working interest owners for permission to publish this paper. This paper reflects the views of the authors, and does not necessarily reflect the views of the authors' respective Companies or other working interest owners.

Nomenclature

ft.	= Feet
in.	= Inch
MD	= Measured Depth
psi	= Pounds (f) per Square Inch
MI	=Miscible Injectant
MIT	=Mechanical Integrity Test
gpm	=gallons per minute
CCL	=Casing Collar Locator
GLM	=Gas Lift Mandrel

Ppg =Pounds per Gallon

References

1. Johns, J., Blount, C., Dethlefs, J., Julian, J., Loveland, M., McConnell and Schwartz, G., "Applied Ultrasonic Technology in Wellbore Leak Detection and Case Histories in Alaska North Slope Wells," paper SPE 102815 presented at the Annual Technical Conference and Exhibition held in San Antonio, Texas, U.S.A., 24–27 September 2006.
2. Rusch, D., Ellis, B., "Use of Pressure Activated Sealants to Cure Sources of Casing Pressure," SPE paper 55996-MS presented at the SPE Western Regional Meeting, Anchorage, Alaska U.S.A. 1999.
3. Gutierrez, D., "BP's Deepwater Intervention Techniques for Maintaining Integrity in Subsea Wells", presented at Subsea Rio Conference, Rio De Janeiro, Brazil, 2004.

SI Metric Conversion Factors

Bbl	x 1.590	E - 01 = m^3
Ft	x 3.048	E - 01 = m
in.	x 2.54	E + 00 = cm
Lbf	x 4.448 222	E + 00 = N
Psi	x 6.894 757	E - 03 = Mpa

Figures

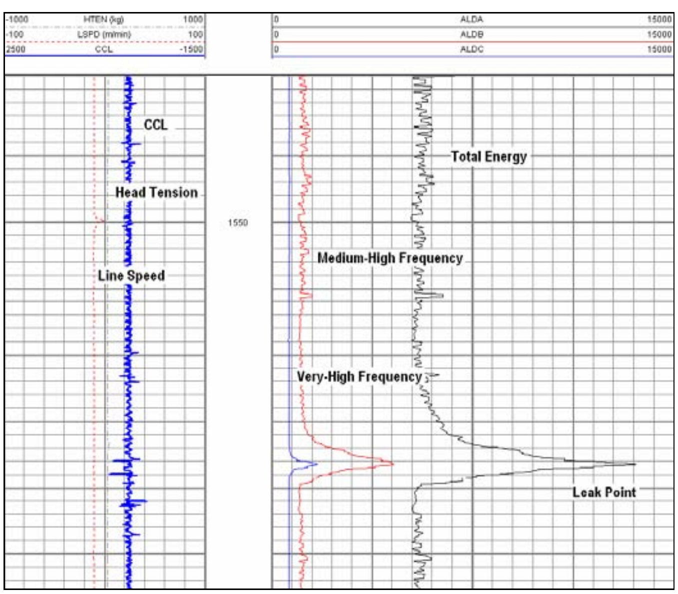

Figure 1: Graphical representing the tool response of the ultrasonic leak detection tool. This illustration demonstrates the frequency response of the tool as it is passed by a leak at typical logging speeds.

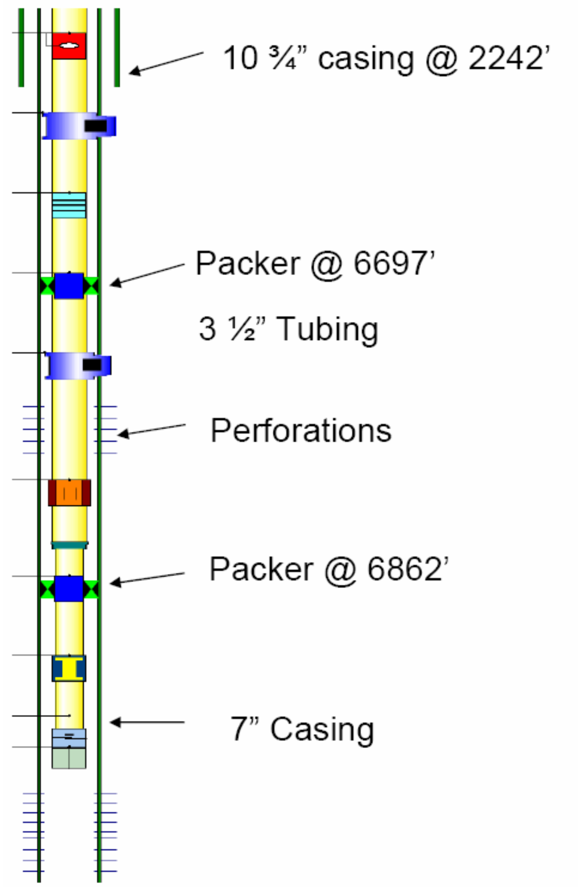

Figure 2: Schematic of Well A.

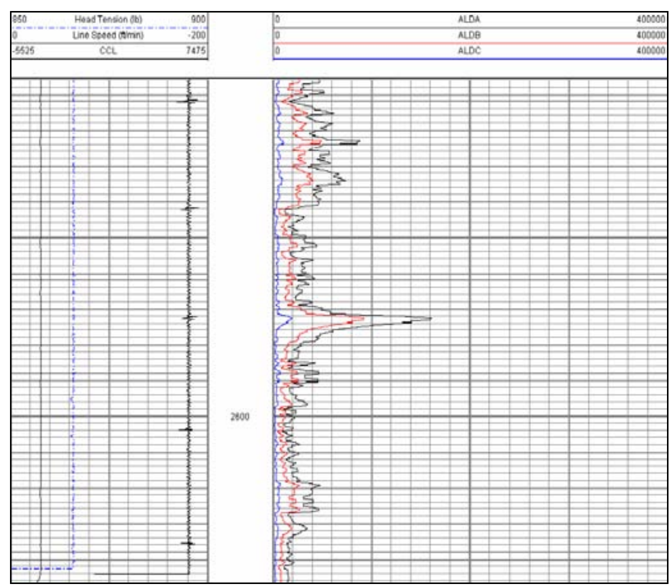

Figure 3: Well A Dynamic log showing casing leak at 2574' measured depth.

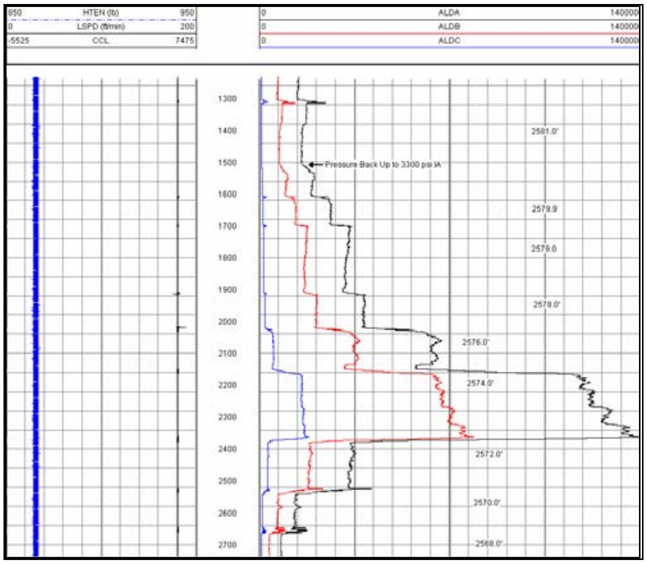

Figure 4: Signal response while taking stationary logs on Well A. Maximum signal strength is shown at 2574'.

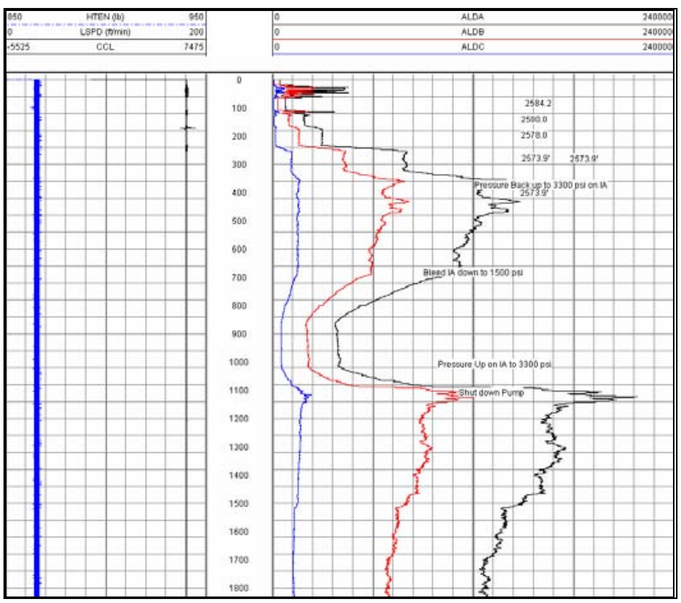

Figure 5: Well A stationary log showing response in signal strength as the pressure is manipulated.

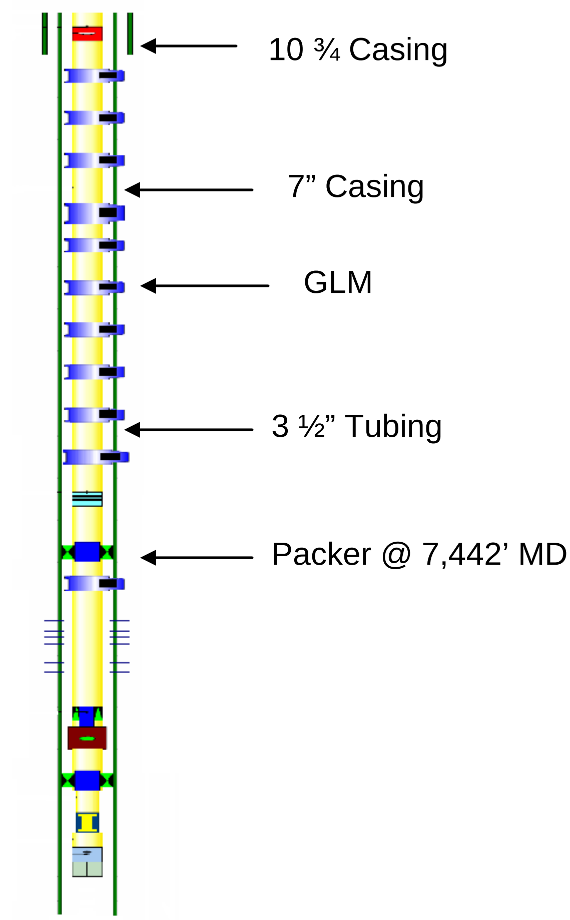

Figure 6: Schematic of Well B.

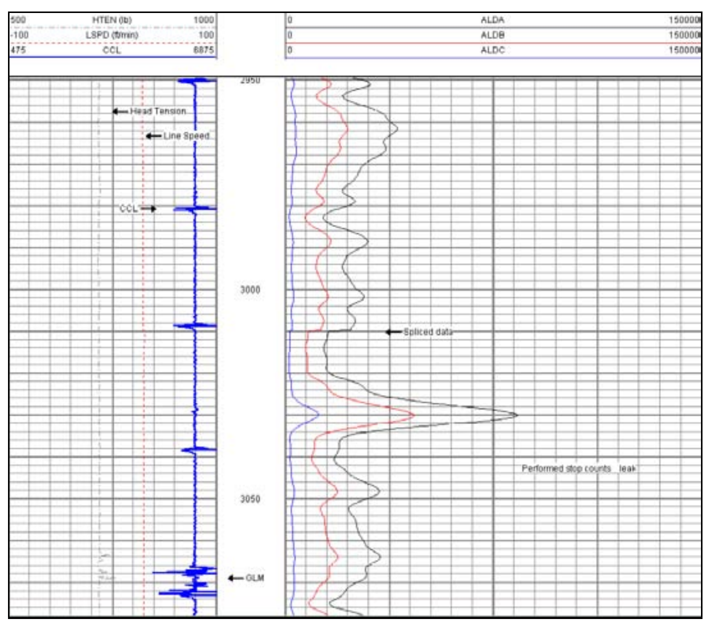

Figure 7: Dynamic log of tubing in Well B with leak at 3,030' MD.

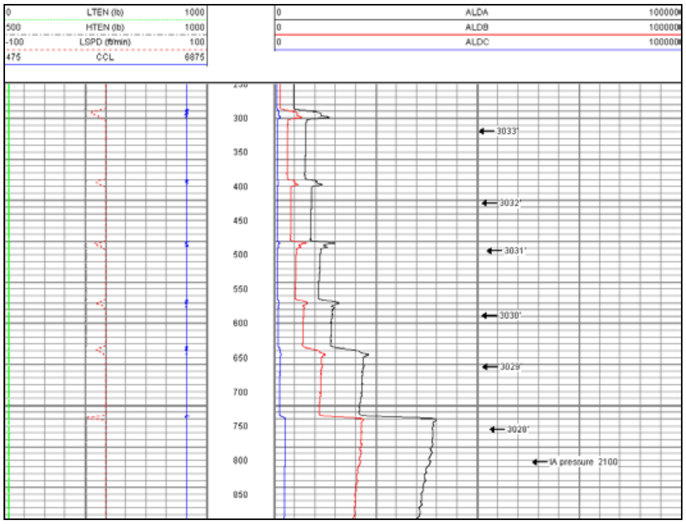

Figure 8: Signal response while taking stationary logs on Well B.

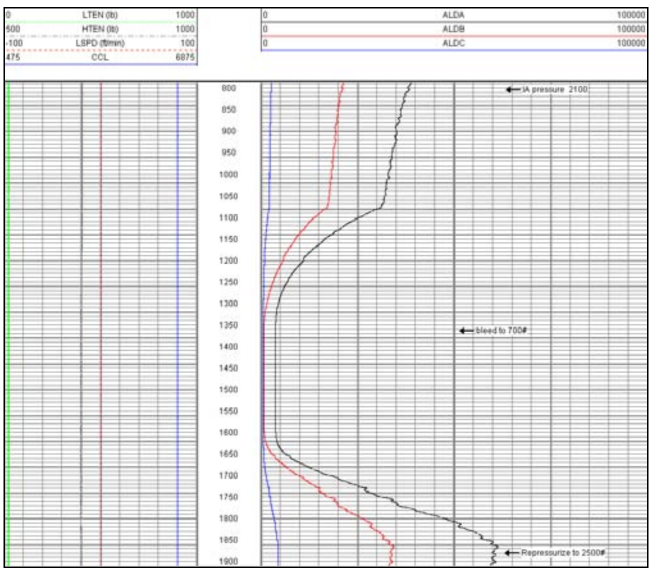

Figure 9: Well B stationary log showing response in signal strength as the pressure is manipulated.

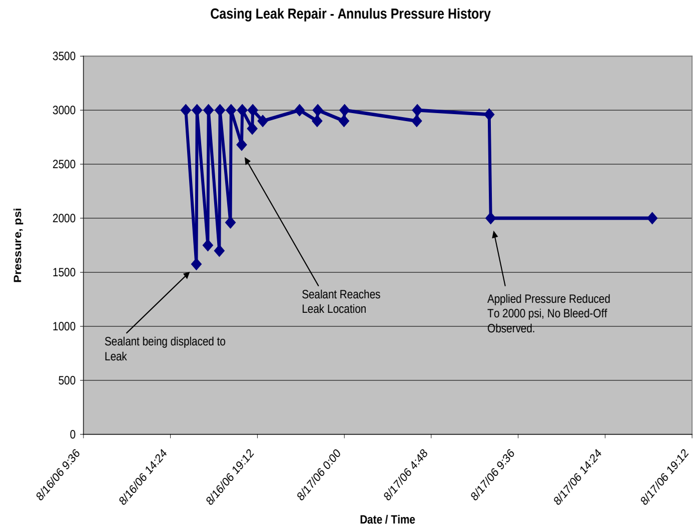

Figure 10: Graph of annulus pressure history during leak repair process.